ME 529 – Advanced Energy Systems
Autumn, 2014

Overview

Energy is one of the key drivers for the modern economy. Our energy industry is based on processes take raw energy resources found in nature (fuels, wind, sunlight, hot geothermal masses) and transform these into forms useful to the economy (electricity, mechanical power, space and process heating). Much of the study of energy focuses on the relationship between heat and work, although it is broader than this.

Modern energy systems are very complex in design. The figure on the following page shows the general flow diagram for a General Electric Class H combined cycle system. These kinds of natural gas fired plants are a significant fraction of the energy technology systems being sold today (here, the transformation is from natural gas fuel to electricity). There are sound technical reasons why this plant is configured as it is, generally focusing on achieving a very high efficiency. This particular design converts 60% of the fuel heating value to electricity (by contrast, a coal-fired Rankine cycle generally as a 37% efficiency). The big question from the students' perspective should by why the design looks as it does, and what methodology does one use to arrive at such a design. This is the root goal of this course.

More specifically, the objectives are:

1. Understand and apply the principles used to find and quantify, and minimize the thermodynamic irreversibilities that occur in these systems. Designing to remove or minimize these is how the engineer is able to reach high efficiency.

2. Ability to use professional grade tools to make these evaluations. This is where we will replace the very simple cycle analysis procedures you used in your undergraduate thermodynamics class (e.g., air standard assumptions, virtual cycles) with more accurate performance evaluation procedures.

3. Survey the major existing and evolving technologies, partly so you will have seen them, and partly using them as case studies to illustrate the preceding two items.

The principles we use to understand cycle design are based on the First and Second Laws. It's worth repeating what they offer in words at this point.

The First Law essentially says that any imbalance in the flow of energy in or out of a system must show up as a change in the energy content of the system (e.g., if more heat flows into a box than leaves it, the box gets hot). This is the same as a checking account for energy. That's fundamentally all there is to it. The rest is just very accurate record keeping.

The Second Law can be stated in a practical way via the following three observations:

- Work represents the transfer of organized energy (*e.g.*, all the molecules moving in an organized direction, as in a rotating shaft). It is more valuable to us than thermal energy, in which the energy is contained in random molecular motions. Work can be directly used to perform useful tasks because the organized motion can be converted into useful tasks such as lifting weights or running a generator.

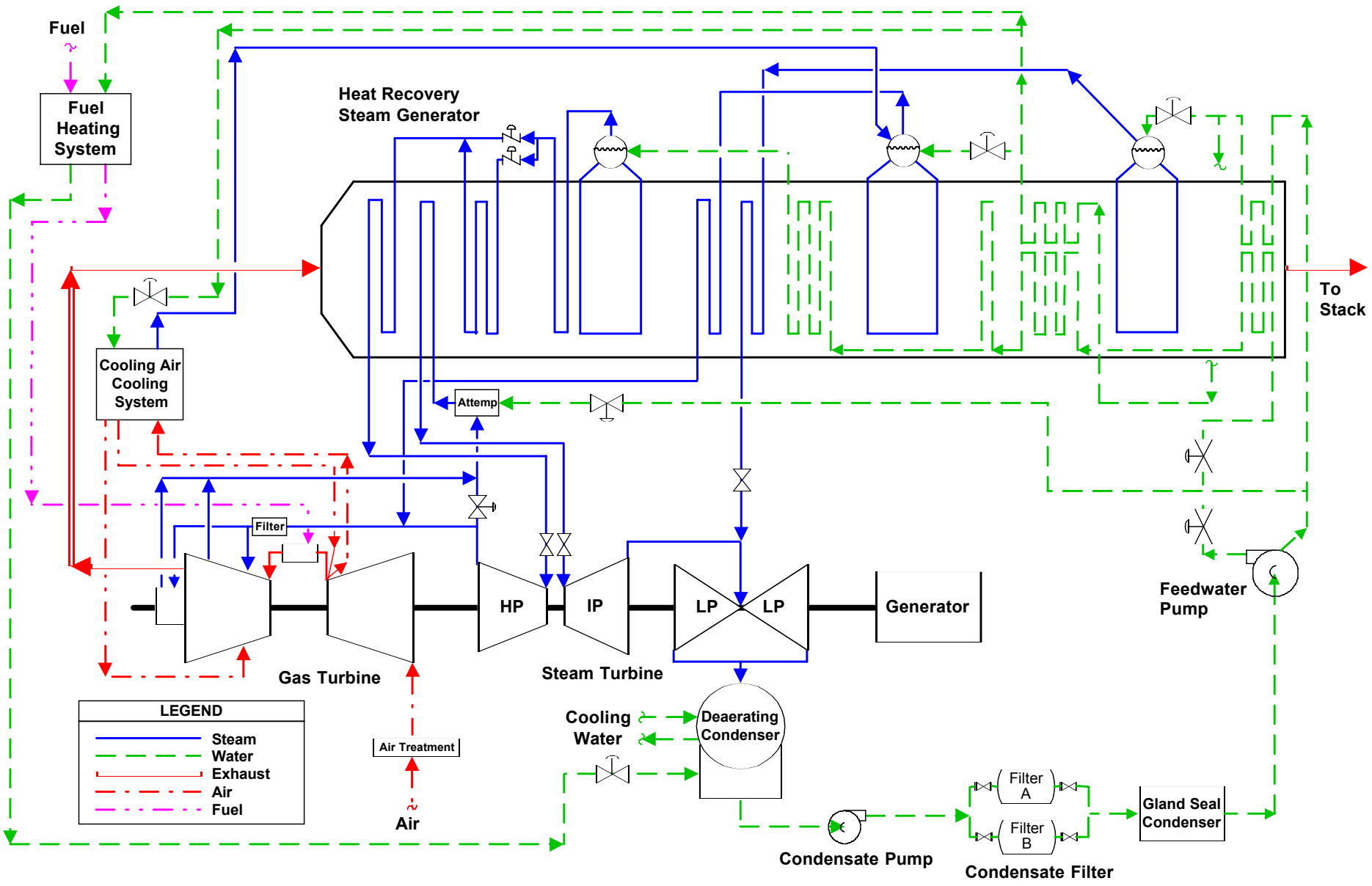

Figure 2. STAG 107H/109H cycle diagram

- A given amount of thermal energy at a higher temperature is more valuable (*i.e.*, it can be used to make more work) that the same amount of energy at a lower temperature. This is not intuitive, but it nonetheless is true.
- All real processes proceed in a direction that degrades the utility of the energy for making work. In other words, organized motion tends to become disorganized/randomized into thermal motion.

These imply the following:

- A portion of the work going into any real process is lost to thermal energy (*e.g.*, friction). This cannot be completely recovered as work and is lost.
- Heat always flows from hot to cold, unless helped by work to go the other way. Moving from hot to cold degrades its utility.
- Power cycles extract thermal energy from a high-temperature reservoir. Part of this is "promoted" by being converted into work (organized energy). This can only be accomplished by moving the rest of this extracted thermal energy to a lower temperature (thereby degrading its utility). In real life, the lost utility of the heat going to the lower temperature exceeds the gained utility of the heat-to-work transition. Thus, while you have some work recovered, the overall work potential of the original heat extracted is reduced.
- To move heat from cold to hot requires the intervention of work. In the best possible refrigeration cycle, the amount of value gained by the energy in moving to a hotter body is exactly offset by the loss of value of the organized work used. This exact balancing of the value of energy is what defines a reversible process.

These principles are important because they are the reasons energy systems are designed in the way they are. A principal goal of this course is learn how to look at complex energy systems as structures that are designed to extract the maximum amount of work potential from a given resource. This is how professionals do performance evaluations on practical energy systems.

Lectures

Lecture notes will be posted on the class website as scanned PDF files shortly after the lecture is given.

Problem Sets

I firmly believe you only really learn and understand this material if you apply it yourself. No matter how clear the lectures or reading may seem, you don't really understand the material until you try to do something with it **on your own**. The problem sets are your principal tool to do this. While working in groups is great for achieving group-oriented goals, you miss out on the opportunity to think the problem through on your own. Although you end up with a good grade on your homework, the problem appears when you sit down to take an exam. So my suggestion is to try the problem sets on you own as much as possible.

Problem sets will be assigned periodically on the website, with due dates depending on the length of the assignment. They are due at 4:30 PM on the due date via a dropbox or other web-based submission procedure. I will be posting solutions on the web immediately after this.

I do ask that you follow a few format standards when you prepare your homework. The main goal is to ensure that we can follow how you worked through the problem. Obviously, this helps us deal with grading a large class. More importantly, the work you prepare for your technical supervisors in the outside world must be clear enough so that they can follow your thinking. A

few tricks will help your do this and will have a first-order impact on your initial career success. These homework format standards will appear in the "Handouts" section of the website.

Exams

About one week ahead of each exam, a set of learning objectives for that exam will be posted on the web. This will give information about the material to be covered, what I will be looking for on the exam, and other logistical information. Distance learning students will be able to take all the exams (including the final) remotely if they choose.

Grading

Grading for the undergraduate (ME 430) and graduate (ME 529) sections is done separately. For such joint classes, the graduate section is supposed to include additional content, and in this case it will include a special project.

The grading scheme is as follows:

Undergraduate (430)

• Homework	150
• Midterms (2@100)	200
• Final	150
Total	**500**

Graduate (529)

• Homework	150
• Midterms (2@100)	200
• Final	150
• Project	100
Total	**600**

The final grades will be based on your class ranking as determined by your percentage of the 500 or 600 total points. There is neither a fixed formula relating the percentage you achieve to your grade nor a grading curve. Instead, the mean grade for each class will be based on my subjective assessment of how well the class, overall, is getting the material. The spread will be based on another subjective judgement on how your individual performance relates to the class average. The class grades will, however, be positively correlated with class rank, *i.e.*, nobody with fewer point than another person will get a better final grade. It is theoretically possible that everybody could get a 4.0.

ME 430/529 Advanced Energy Systems

Autumn 2014

Text: Any standard thermo text (*e.g.*, Cengal and Boles). Will supplement with handouts, web materials, *etc*.

Schedule: Monday, Tuesday, Wednesday, Friday 2:30 to 3:20 PM. MTWF: Loew 206

Calendar: This indicates tentative topic coverage

Final Exam: Tuesday, December 9, 2:30 to 4:20 PM

Instructor:

Prof. John Kramlich
MEB 319
Office Hours: Monday, Wednesday 3:30-4:30 PM, Friday 9:00-10:00 AM
kramlich@uw.edu
206-543-5538

TA:

Anamol Pundle
MEB 107
Office Hours: Tuesday, Thursday 4:00 - 5:30 PM,
apundle@uw.edu

Website:

http://courses.washington.edu/mengr430/au14
(not active yet)

	Monday	Tuesday	Wednesday	Friday
Sept.			24 Course Intro Fundamental Principles	26 Review: Rankine and Brayton Cycles
	29 Availability, Reversible Work	30 Irreversibility & Fuels/Combustor Chemistry	1 Reacting First Law/ Equilibrium	3 Equilibrium/ Chemical Availability
October	6 Combined Cycle, Basic Design	7 Combined Cycle, Brayton Portion	8 Combined Cycle, Rankine Portion	10 Combined Cycle, HRSG Design
	13 Advanced Cycles: 2 & 3 Pressure Systems	14 Combined Cycle Economics, Technology	15 US Energy Overview	17 Solid Fuel Combustion Technology/ Biomass
	20 Environmental: NOx	21 Environmental: NOx	22 Exam #1	24 Environmental: SOx
	27 Environmental: Particulate Matter	28 Environmental: Greenhouse & Sequestration	29 Nuclear: Energy Balances	31 Nuclear: Reactions
November	3 Nuclear Decay, Fission	4 Neutron Speeds/Cross Sections/ Moderation	5 Reactor Population Balances	7 Nuclear Reactor Design
	10 Nuclear Accidents, Weapons, Proliferation	11 Veterans Day	12 Raw Biomass Fuel Characteristics	14 Black Liquor Processing
	17 Combustion Fluidized Beds	18 Biomass Fuel Refining: Overview	19 Exam #2	21 Fuel Cell Overview, Electrochemistry
	24 Nernst Potential Overpotentials	25 PEM Stack Design	26 PEM Design & Operation	28 Thanksgiving
Dec.	1 Fuel Cell Types	2 Solid Oxide Cells, Integrated Systems	3 Fuel Sources: Reformers	5 Course Review